Understanding the Spatiotemporal Distribution of Soil Moisture at the Santa Rita Experimental Range

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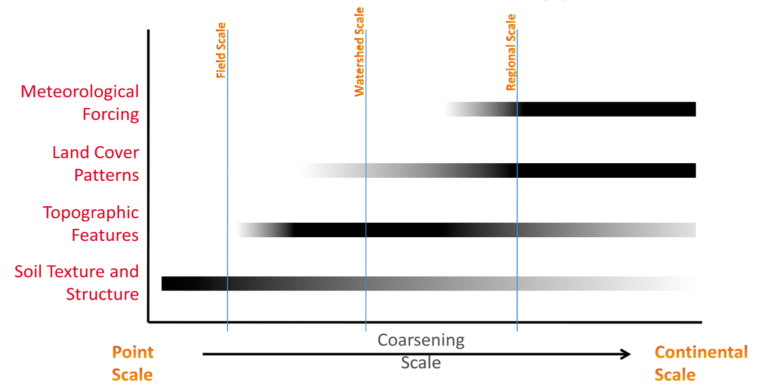
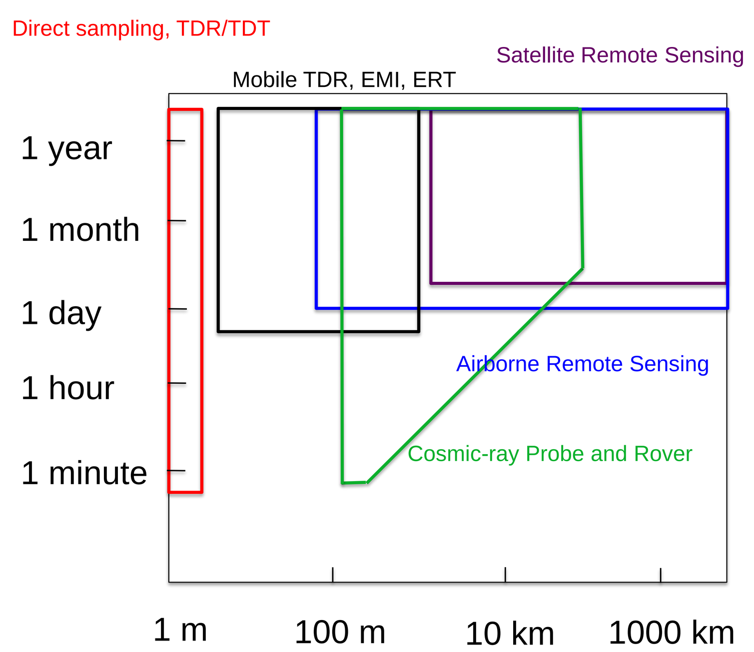
1. Introduction

The spatiotemporal distribution of soil moisture is critical for understanding the water, energy, and carbon cycles. Moreover, in drylands soil moisture is intimately linked to rainfall recycling shown through autocorrelation with future events. However, measurement scales of soil moisture often do not align with measurements of energy and carbon flux making a mechanistic understanding difficult. The three main problems are: 1) direct measurements are time and labor intensive at large scales, 2) the natural variability of soil moisture makes it difficult to interpret point measurements of soil moisture to larger scales, and 3) the controls of soil moisture organization change with spatial scale. Here we investigated how direct and indirect measurements of soil moisture indicate how it is organized across scales and correlates with energy and carbon fluxes.



Controls and their importance on the organization of soil moisture across spatial scales (Crow et al. 2012).



Space time diagram of direct and indirect measurement techniques used to characterize soil moisture (adapted from Robinson et al. 2008). At SRER we used direct sampling, time domain transmission (TDT), electromagnetic induction (EMI), and a cosmic-ray neutron probe (CRP).

2. Experimental Design

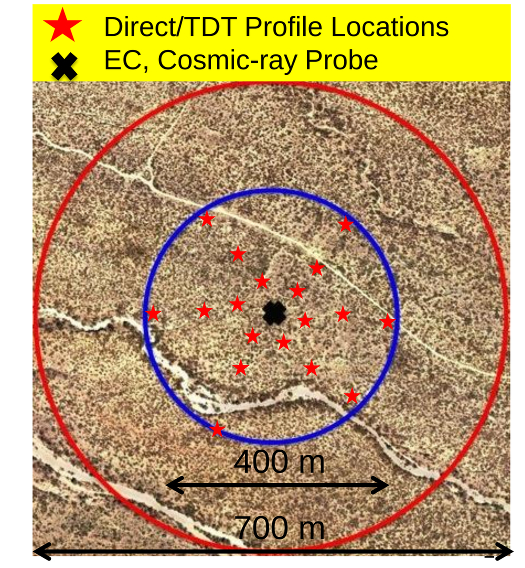
At the SRER creosote eddy covariance (EC) flux tower site we collected footprint soil moisture information between July 2010 and August 2013 using:

Direct sampling- 9 times

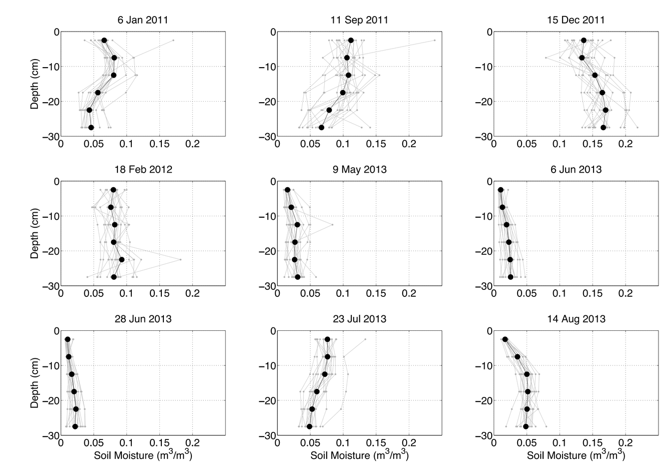
Time-domain transmission (TDT)- July 2011-present

Electromagnetic induction (EMI)- 4 times

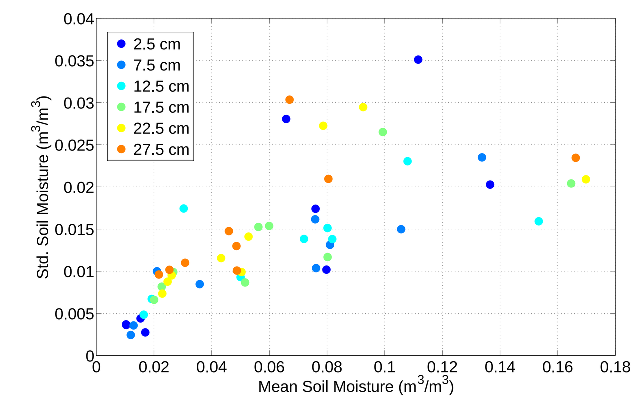
Cosmic-ray neutron probe (CRP) CRP-July 2010-present



Locations of 18 direct/TDT sampling points around EC tower and CRP. The 18 locations (every 60° and radii of 25, 75, 200m) were chosen to correspond with the sensitivity of the CRP.



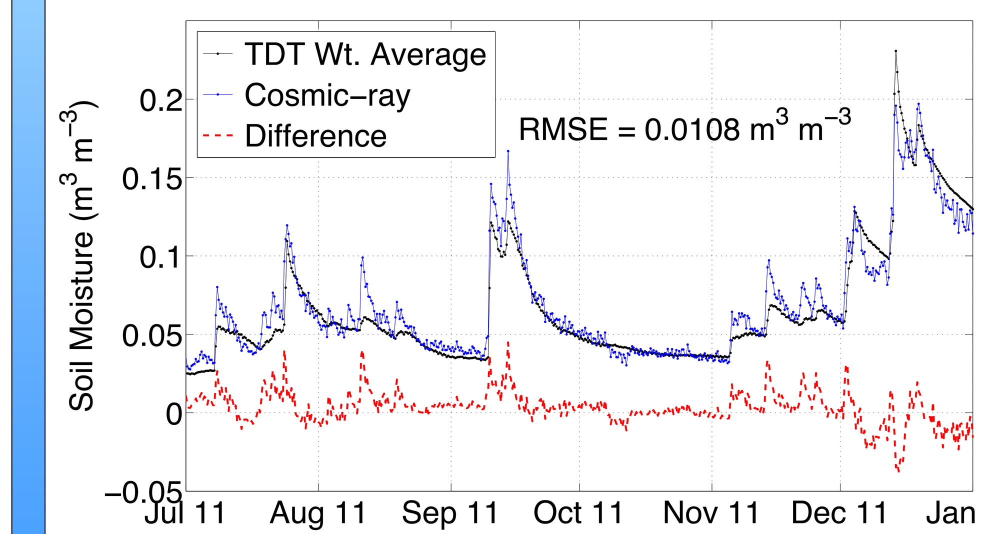
Direct sampling of soil moisture showing individual (grey) and average (black) profiles collected around the footprint. Figures illustrates large range of individual profiles but well behaved average profile.



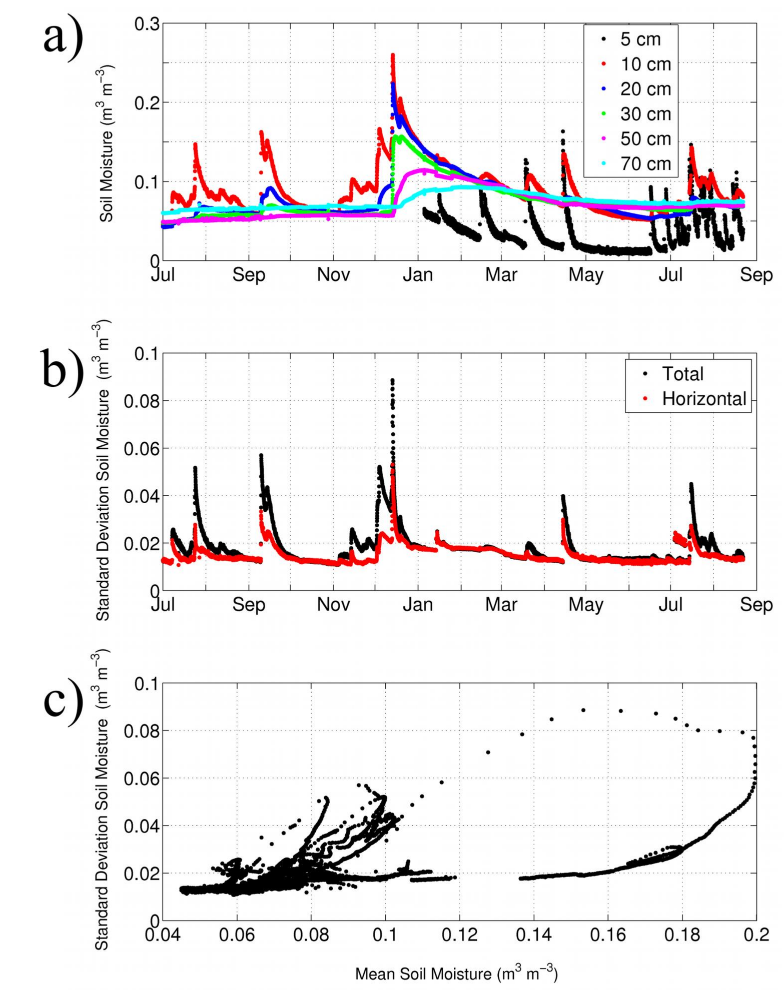
Relationship between footprint average soil moisture and standard deviation organized by depth. Relationship shows inverted parabolic shape seen elsewhere (c.f. Crow et al. 2012).

3. TDT Soil Moisture Observations

Following calibration, the comparison of average footprint soil moisture between TDT and CRP indicates a low RMSE around probe industry standards of <0.02 m³/m³. The TDT data provide a more complete picture of how the mean and standard deviation of soil moisture are organized around the footprint.



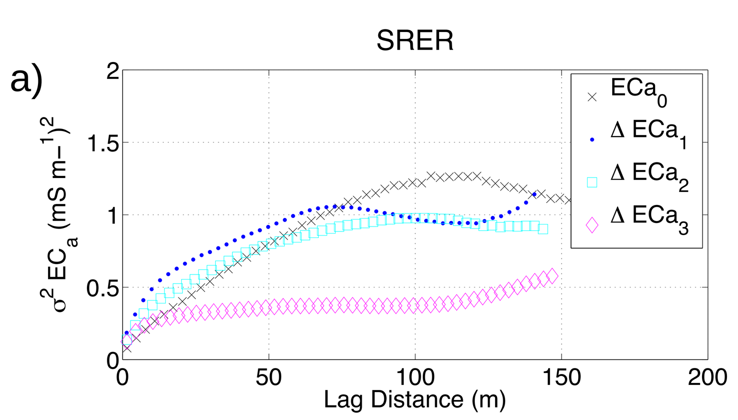
Comparison of average footprint soil moisture between TDT sensors and CRP. Because of the correlation in the difference between the two signals a 5 cm sensor was added in Jan 2012 (Franz et al. 2012).

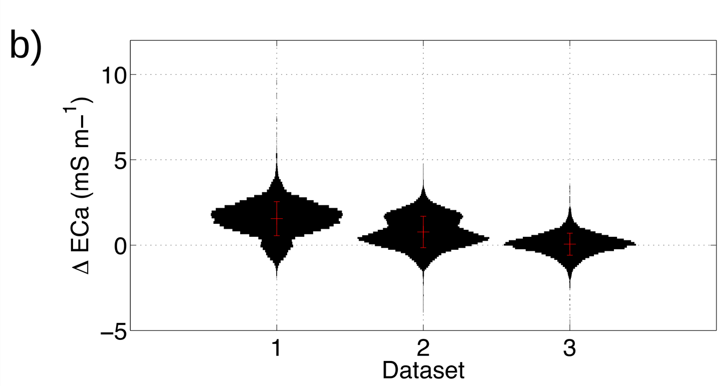


a) Footprint average soil moisture organized by depth from July 2011 to August 2012, b) horizontal and total soil moisture standard deviation, and c) relationship between total standard deviation and mean soil moisture illustrating inverted parabolic shape and hysteresis in relationship following wetting (top loops) and drying cycles (bottom loops) (Franz et al. In press).

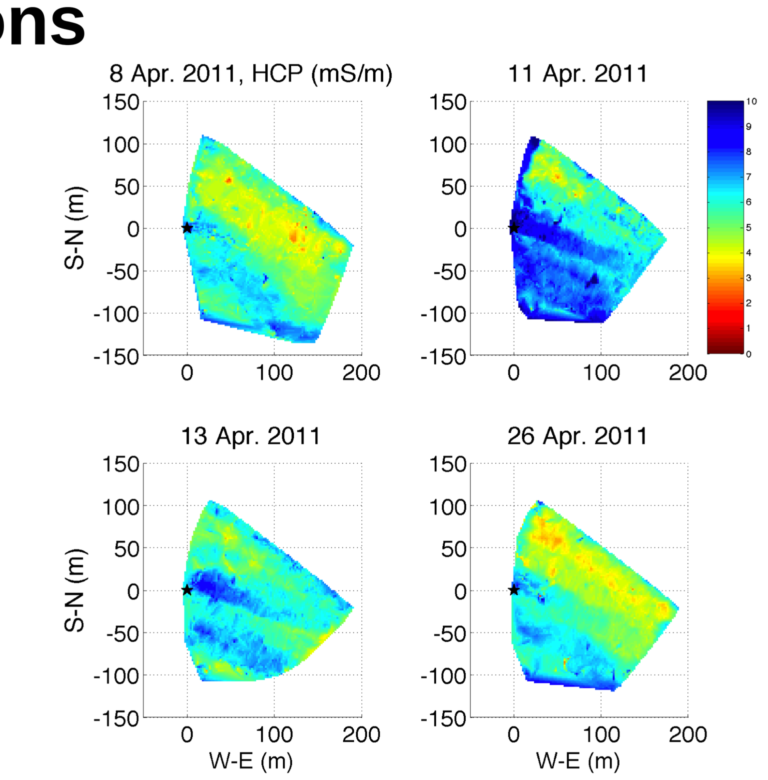
4. EMI Soil Moisture Observations

Because of the limited spatial coverage of direct sampling and TDT measurements we used time-lapse observations of bulk electrical conductivity (ECa) as a proxy for changes in soil moisture. The extensive spatial coverage allows us to examine how soil moisture is organized within the footprint.

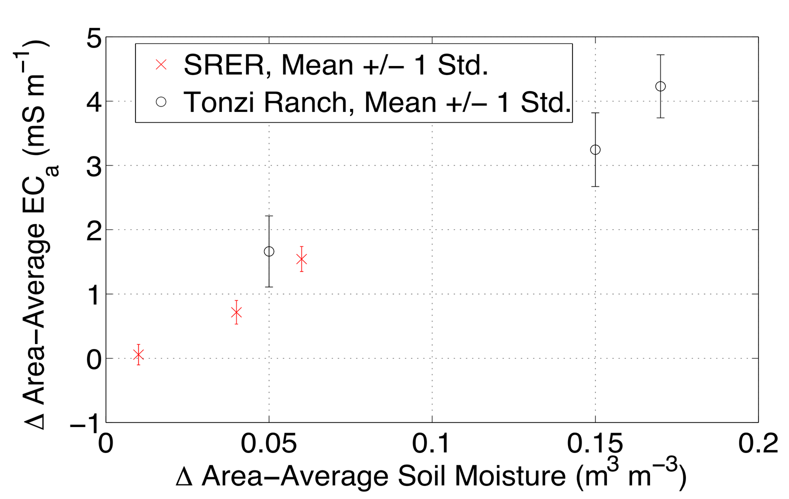




a) Semi-variogram of the change in ECa (as a proxy for soil moisture) following different time periods since last rainfall and b) violin graphs showing the distribution of the change in ECa within the footprint. The organization of soil moisture, defined here as the semi-variogram sill and range and distribution of the change in ECa, is controlled by site topography, soil texture, and their interaction.



Measurements of ECa (mS/m) before and after a 10 mm 9 April 2011 rain event using EMI. The black star indicates the location of the CRP.



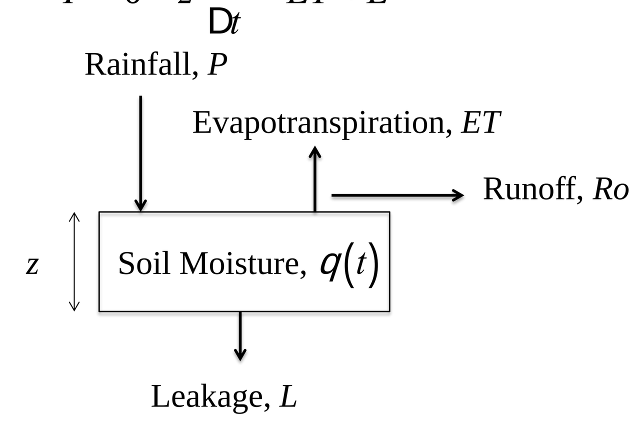
Comparison of footprint average soil moisture from the CRP and footprint average change in ECa from EMI. By establishing this site specific petrophysical transform we will be able to convert from ECa into soil moisture. ECa is also a function of soil temperature and soil cations making the ECa data of soil moisture less certain but still elucidating the spatial structure of soil moisture.

5. Estimates of Footprint Water Flux

Cosmic-ray Neutron Probe

$$P > 0 \qquad z\frac{\Delta\theta}{\Delta t} = Peff \qquad Ro = P - Peff$$

$$P = 0 \qquad z\frac{\Delta\theta}{\Delta t} = ET + L$$

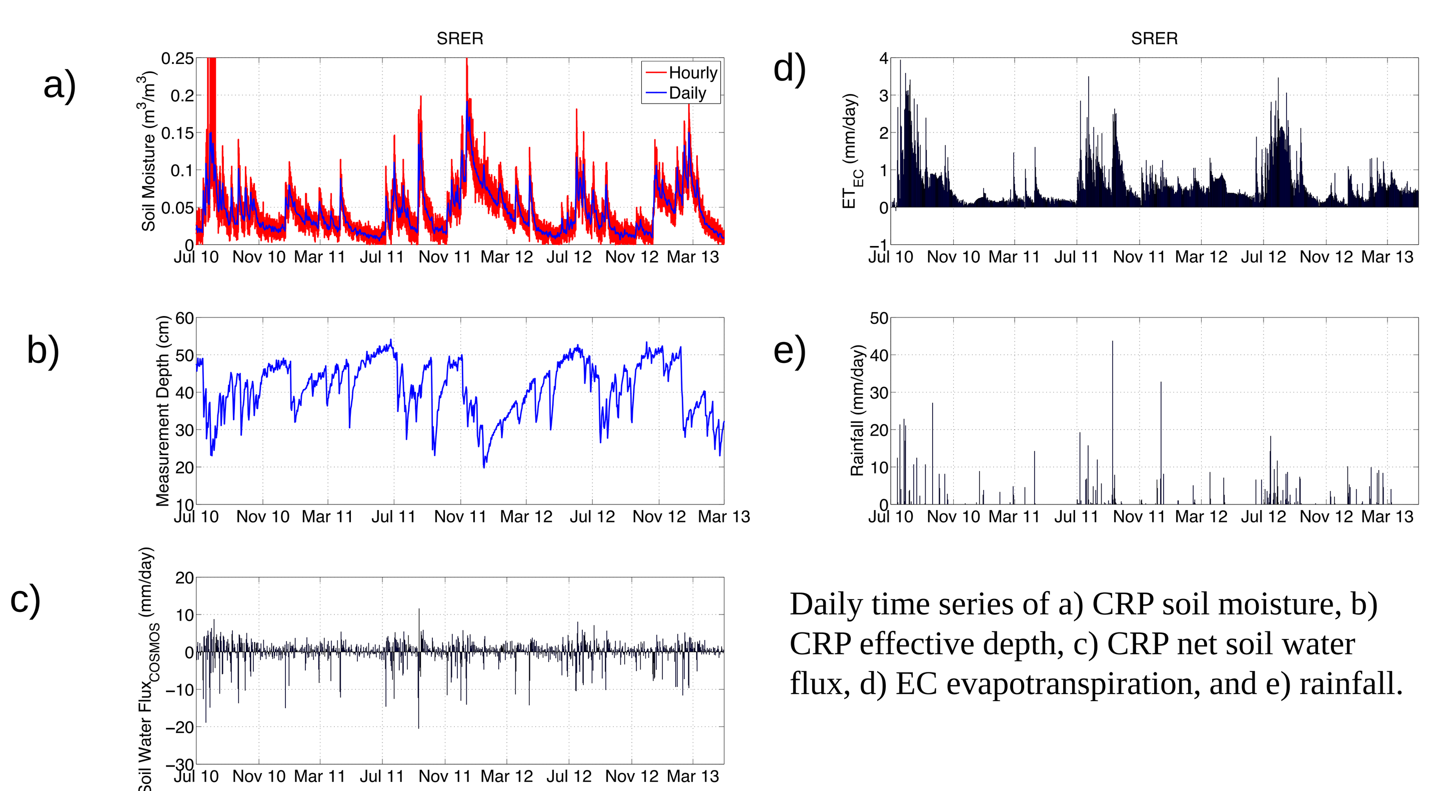


Simplified control volume, state variable, and fluxes for estimating the ecosystem water balance.

Eddy Covariance

$$ET = \sum_{i=1}^{48} \frac{1800 * 1.25 * LE_i}{\left[(2.502 - 0.00237 * Ta_i) * 10^6\right]}$$

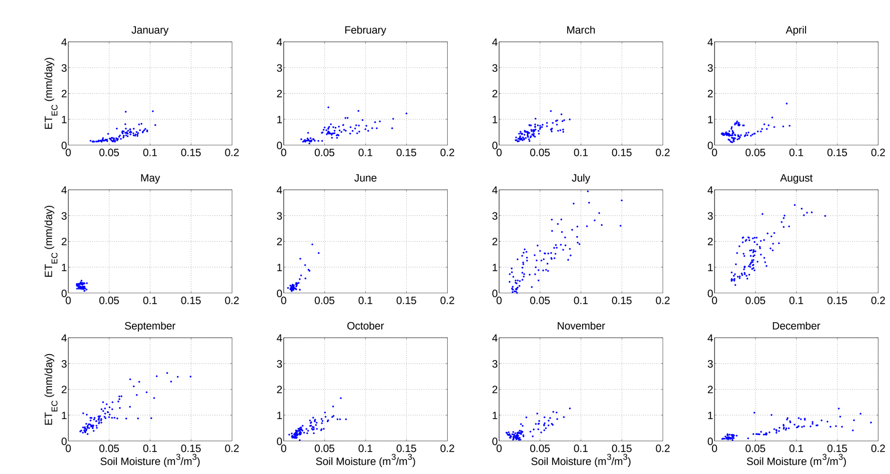
Where, ET (mm/day) is the daily evapotranspiration, LE (W/m²) is the half hourly corrected latent energy flux, Ta (°C) is air temperature at the surface used to correct the latent heat of vaporization, and the remaining constants are used for unit conversion.



Daily time series of a) CRP soil moisture, b) CRP effective depth, c) CRP net soil water flux, d) EC evapotranspiration, and e) rainfall.

6. Correlation of Footprint Soil Moisture and Water Flux

Assuming the spatial scales between CRP and EC are comparable, we are able to provide scatter plots of footprint scale soil moisture and evapotranspiration (ET). These data will be useful for better parameterizing land surface models and helping understand how mesoscale or regional climate patterns will affect local ecosystem structure and function.



Monthly scatter plots of daily average soil moisture from CRP and daily evapotranspiration from EC.

7. Conclusions

- Soil moisture is controlled by a variety of factors across scales which are difficult to quantify with direct observations thus limiting our understanding of how ecosystems function
- Geophysical instruments helped us to quantify the footprint scale mean, standard deviation, and spatial structure of soil moisture at SRER
- Footprint scale CRP estimates of soil moisture correlate well with EC ET, providing a useful dataset for future land surface and mesoscale modeling studies

8. References

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9. Acknowledgments

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